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Production of biofuel from fruit and vegetable wastes

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Abstract

This research examines the potential of exploiting organic wastes, specifically fruit and vegetable wastes, as an alternative source for biofuel production, as part of the search for sustainable solutions to energy and environmental challenges. The research focuses on studying the feasibility of producing bioethanol from fruit and vegetable wastes,.The research aims to identify best practices for improving production processes and assessing the environmental and economic impact of using this waste. Initial results indicate that organic waste represents a promising source for biofuel production, offering the potential for tangible environmental and economic benefits. This research presents a practical experiment for extracting bioethanol from inedible fruits(banana, apple and orange) wastes and inedible vegetables (potato, beet and carrots)wastes. The experiment involves three main steps: juice preparation, yeast fermentation, and distillation. The purity of the produced ethanol is then confirmed through chemical tests.

Key Words: Fruit wastes, Vegetables wastes, Biofuel, Bioethanol, Pre-treatment,Fermentation,Distillation,Recycling.

1.Introduction:

Despite the well-documented harmful environmental effects of fossil fuels—such as the release of greenhouse gases that alter the climate—they still dominate global energy consumption. In the next two decades, CO_2 emissions are expected to double, with total greenhouse gas (GHG) emissions exceeding 40 billion metric tonnes, leading to potentially irreversible climate changes[1],[2],[3]. Moreover, poor management and disposal of waste and wastewater also pose serious threats to both the environment and public health. Aquatic systems are at risk due to the discharge of untreated wastewater that contains toxic substances or from the failure of treatment plants to effectively eliminate pollutants. [4],[5],[6] .

Because of these concerns, there is a pressing need to find sustainable, easily producible energy alternatives, preferably derived from waste or residues that serve as renewable raw materials for second-generation biofuels. Additionally, research must aim to reduce the environmental impact and energy intensity of biomass-to-energy conversion processes.

In short, renewable energy should be accessible and production methods should be both ecofriendly and economically viable.[7],[8],[9].

Switching from aerobic to anaerobic biological processes could take advantage of the abundant daily production of organic waste, recovering organic material as biogas. This biofuel can be used directly for energy or refined into high-grade methane suitable for sale in transportation or energy markets

The Organic Fraction of Municipal Solid Waste (OFMSW) includes three main types: green waste (from garden maintenance), food waste (from households and businesses like restaurants), and market waste (MW), primarily made up of fruit and vegetable residues like peels, rotten produce, and potato or onion scraps. MW is particularly abundant and easy to separate, even in areas with basic waste systems, and is ideal for biogas production due to its high moisture and carbohydrate content. However, easily degradable sugars convert quickly into volatile fatty acids (VFAs),whose buildup can disrupt the process and reduce biogas yield. Introducing a nitrogen-rich source to balance the high carbon-to-nitrogen (C/N) ratio of MW could help improve methane production and stabilize the biological process.

According to the United Nations, around 40% of food produced in India is wasted or lost each year. India's Ministry of Food Processing reports an annual agricultural loss worth 580 billion rupees. The country is the top fruit producer globally, and each year, 12 million tonnes of fruits, 21 million tonnes of vegetables, and 23 million tonnes of food grains are lost, valued at about 240 billion rupees.[10],[11].

Bioethanol offers several benefits over traditional fossil fuels. It is sourced from renewable materials, particularly crops that grow well locally. A key advantage over fossil fuels is the reduction in greenhouse gas emissions, as bioethanol crops absorb CO_2 during growth, partially offsetting emissions from fuel use. Mixing bioethanol with gasoline can prolong national oil reserves and enhance energy security by reducing dependency on oil-exporting countries. Promoting bioethanol usage could also stimulate rural economies by increasing demand for crop cultivation.

(1) Furthermore, bioethanol is biodegradable and significantly less toxic than fossil fuels. Using it in older engines can lower carbon monoxide emissions, thereby improving air quality. Another benefit is its compatibility with current fuel infrastructure: bioethanol can be blended up to 5% with petrol without requiring engine modifications. Common production methods like fermentation make fruit waste an affordable, readily available raw material for bioethanol, typically fermented using *Saccharomyces cerevisiae*. Ethanol, or ethyl alcohol (C_2H_5OH), is a clear liquid made naturally by yeast fermentation of sugars or through petrochemical methods. It serves numerous roles: as a solvent, disinfectant, and in medicine as an antiseptic.

(2) The largest single application is as motor fuel and fuel additive. Unlike petroleum, ethanol is renewable and can also be produced from animal waste. Ethanol fuel is mainly used as a gasoline additive. It enhances fuel's octane rating and replaces lead-based additives. Ethanol blending adds oxygen to fuel, enabling more complete combustion and reducing emissions. Ethanol-blended fuels, like E10 (10% ethanol, 90% petrol), are widely available in the U.S. Standard engines can use E10 without modification, and warranties remain valid. Only flexible-fuel vehicles can use high-ethanol blends like E85 (85% ethanol, 15% petrol).[12]

Potential of apple, orange, and banana waste for producing bioethanol production from banana waste: production, is rich in fermentable sugars and has been researched for bioethanol production. The standard process involves enzymatic hydrolysis to release sugars, followed by fermentation with yeast strains such as Saccharomyces cerevisiae. While specific studies were not mentioned in the available sources, prior known to contain a considerable amount of carbohydrates, making it a potential source for bioethanol. The process typically involves breaking down complex carbohydrates into fermentable sugars through hydrolysis, followed by fermentation with microorganisms like Saccharomyces cerevisiae to produce ethanol.
However, further research is necessary to refine these methods and assess their viability for large-scale industrial application.

Orange Waste: Orange waste has been: widely studied for biofuel production due to its high levels of fermentable sugars and essential oils. A study published in Biofuels explored the steam explosion pretreatment of orange waste, followed by fermentation using Saccharomyces cerevisiae and Clostridium acetobutylicum. This process produced 4.1 g/100 mL of bioethanol and 19.5 g/L of biobutanol. Furthermore, research published in the Journal of the Brazilian Chemical Society showed that enzymatic hydrolysis of orange waste, followed by fermentation with Saccharomyces cerevisiae, also resulted in high ethanol yields. In addition, orange peel extract has been used as a substrate for producing lipids through oleaginous yeasts, which can later be converted into biodiesel. Studies found that Rhodosporidium toruloides and Cryptococcus laurentii produced significant lipid concentrations when grown on orange waste.

Apple Waste: Apple pomace, which is the solid residue from apple juice promising feedstock for bioethanol production, offering a potential solution for waste valorization and renewable energy generation.

research suggests that apple pomace is a Composition of Wastes:

3

-Banana Waste: High in starch, cellulose, and sugars.
-Orange Waste: Rich in limonene (a terpene), pectin, and sugars.
-Apple Waste: Contains significant amounts of sugars and fiber

<u>Potential of potato,carrot and suger beet waste for producing bioethanol</u>

Potato Waste: Potato processing industries produce significant amounts of waste, especially potato byproducts. Research has shown that these wastes can be efficiently converted into bioethanol. One study published in Elsevier described a biorefining process where potato waste underwent organosolv pretreatment followed by enzymatic hydrolysis, resulting in the production of 224.2 grams of ethanol per kilogram of dry potato waste. Additionally, the remaining solids were subjected to anaerobic digestion, generating 57.9 liters of biomethane per kilogram of dry waste, further improving the overall energy output.

Another study focused on potato starch waste for bioethanol production. Using Saccharomyces cerevisiae for fermentation, the process achieved notable ethanol yields. This approach not only provides a sustainable method for bioethanol production but also addresses the disposal challenges associated with potato processing.

Carrot Waste: Carrot waste has also emerged as a promising feedstock forbioethanol production. A study published in Elsevier examined the enzymatic hydrolysis of carrot bagasse, which, after treatment with specific enzymes, resulted in a 3.5-fold increase in fermentable sugar concentration.

This process produced approximately 77.5 liters of ethanol per ton of discarded carrots, with the leftover bagasse potentially usable as animal feed.

Sugar Beet Waste: Sugar beet pulp, a byproduct of sugar extraction,contains high levels of fermentable carbohydrates. Several studies have investigated its potential for bioethanol production. For example, integrated hydrolysis and fermentation processes applied to sugar beet pulp resulted in an ethanol yield of 0.1 grams per gram of dry weight, with an efficiency rate of 49%.

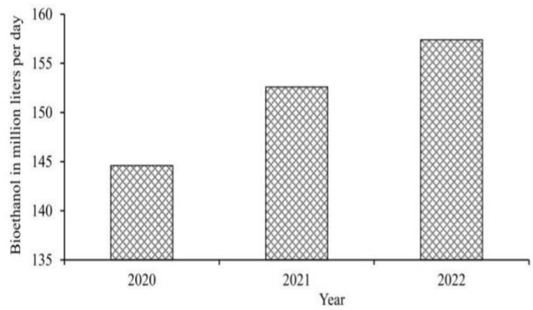


Fig. 1. Global bioethanol production [13].

2.Methods of Research and the tools used[19],[20],[21],[22],[23],

<u>Equipments, apparatus and chemicals</u>

1- Non-freash fruits(apple,panana,orange).
2-Non-fresh vegetables(beetroot,potato, Carrot).
3-Blender or food processor.
4– Active dry yeast [Saccharomyces cerevisiae].
5– Cheesecloth or strainer.
6– Distillation setup.
7- Heater.
8- Iodine.

9- Sodium hydroxide.
10-Potassium dichromate.

3-Experimental:

As we decided to produce an bioethanol from vegetables and fruits that are no longer edible.This process involves several steps…

At first we brought the raw material that we used in this experiment.

The raw materials that was non-fresh fruits(apple,panana,orange) and non-fresh vegetables (beetroot,potato,carrot) and some dry yeast.
And then we use a 3 main steps which are: **pre-treatment,fermentation, and distillation**.[24],[25],[26],[27]

1-Pre-treatment:

The collected fruit and vegetables is washed,chopped into small pieces and blended with the grinder,a pure juice is collected from fruits and vegetables the mass,volume and density was measured and recorded.

2-Fermentation:

added a measured amount of S.cerevisiae (yeast) to each bottle the fruits juice and vegetables juice We covered both bottles, sealed them tightly, and placed them in a warm location resembling an incubator at a temperature of approximately 30°C for four days. As showing in (fig 1)

3-Distillation(Separating ethanol from the mixture):-

We made a simple device to perform the distillation process using some basic tools (plastic bottle, thin plasic tube , glass bottle , metal pot , ice , heater).(fig2,3)

- After fermentation, we heated the mixture in a water bath to prevent the complete evaporation of ethanol. However, the boiling point of ethanol is 78°C (172°F).

-The ethanol produced from the distillation process was collected in a small beaker,

We repeated the distillation process to ensure the purity of the ethanol sample, and the alcohol percentage was calculated using the following equation [28],[29],[30]

$$\% \left(\frac{v}{v}\right) alcohol = \frac{SG1 - SG2}{0.0074}$$

SG1 and SG2 are the specific gravities before and after fermentation, respectively.

Fig2,3 the distillation process

*The method we used demonstrates a sustainable approach to utilize organic waste for biofuel production.

-After extracting the ethanol from the mixture, we conducted some confirmatory experiments to ensure the purity of the ethanol obtained from the experiment

1-Ignition Test: (fig4)

This test is used to test the flammability of a -substance.

-Ethanol is flammable, so this test can be used to detect it.

- A blue flame indicates the presence of ethanol.

(fig4) Ignition Test

2- Iodoform Test:

(fig5) iodoform test

-This test identifies ethanol or secondary alcohols with a CH3CH(OH)- group.

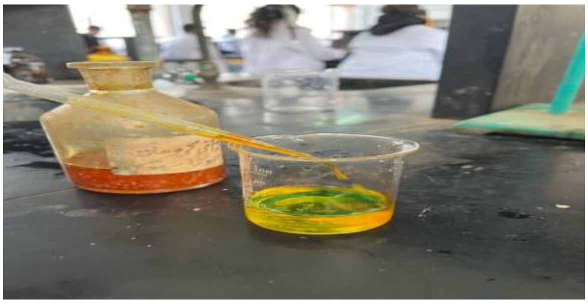
-It involves adding iodine and sodium hydroxide solution, then gentle heating.
-A yellow precipitate of iodoform indicates ethanol presence.

3- Oxidation with Potassium Dichromate:-

-Ethanol reacts with acidified potassium dichromate,

- changing the solution from orange to green.

-This color change signifies ethanol oxidation to acetic acid.



(fig6)

(How to Determine the Heat of Combustion of Ethanol in a Simple Way):

The heat of combustion of ethanol can be determined using a calorimeter experiment by following these steps:[31] (fig7)

Experimental Steps:-

1-Measure the amount of water: Pour a known amount of water (e.g., 100 mL) into the metal .
2-Record the initial temperature: Use the thermometer to measure the initial temperature of the water before heating.
3-Burn the ethanol: Light the alcohol burner under the cup and allow it to heat the water.
4-Measure the final temperature: After a certain period (when heating stops), measure the final temperature of the water.
5-Determine the burned ethanol mass: Weigh the alcohol burner before and after combustion to calculate the amount of ethanol consumed
6-Calculate the heat of combustion: Use the following equation, Q = m.c.delta T

Required materials:

-A glass cup to act as a calorimeter.
-A scale to measure the mass of burned ethanol (ethanol as a fuel source).
–An alcohol burner or a wick soaked in ethanol.
–A metal stand to hold the cup.
–Water and a measured cup.
–A thermometer.

(fig7) The heat of combustion of ethanol

After calculating the amount of heat using the equation Q = m.c.delta T, we measured the heat of combustion of ethanol

Heat of combustion defined as: the amount of heat released when one mole of a substance is completely burned in excess oxygen under standard conditions of temperature and pressure. It is usually measured in kilojoules per mole (kJ/mol).

As we calculated the mass of burned ethanol we get the number of burned ethanol moles then we use all this data and calculate the heat of combustion of the ethanol that produces from our experiment.

4-Results and discussion:

We selected fruits (banana, apple, and orange) and vegetables (carrot, potato, and beetroot). We measured the mass, volume and density of each fruit and vegetable solutions separately before and after fermentation.

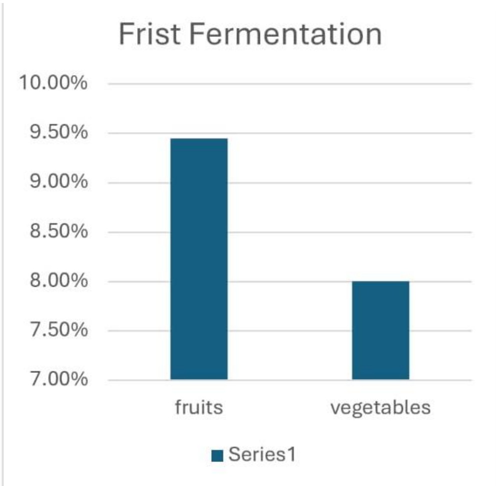
After distillation process we use this equation to calculate the percentage of ethanol in each of the solutions:

$$\% \left(\frac{v}{v}\right) alcohol = \frac{SG1 - SG2}{0.0074}$$

SG1 and SG2 are the specific gravities before and after fermentation, respectively.

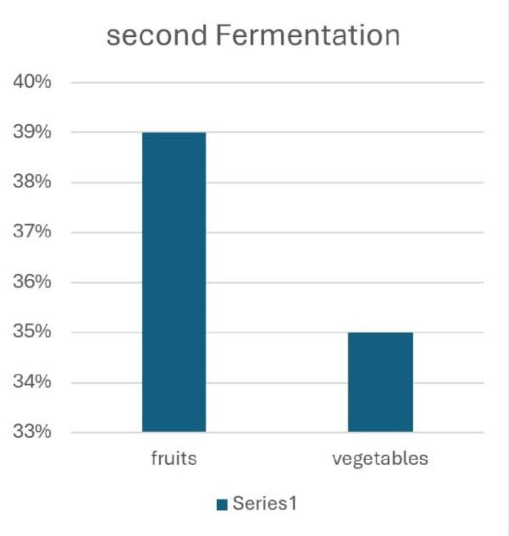
First fermentation results:

	Fruit	Vegetable
Density before	1,08gm/ml	1,08gm/ml
Density after	1,01gm/ml	1,01gm/ml
ABV%	9,18%	7,87%
Alcohol %	9,45	8%



Second fermentation results:

	Fruits	vegetables
Density before	1,08gm/ml	1,08gm/ml
Density after	1,01gm/ml	1,02gm/ml
ABV%	9,18%	7%
Alcohol%	39%	35%



The results of the experiment demonstrated that the ethanol concentration extracted from fruits was greater than that obtained from vegetables. This difference can be attributed to the higher levels of fermentable sugars present in fruits compared to vegetables, a finding that has been consistently supported by various scientific studies.[32],[33],[34]

5.Confimaritry tests:

- Ignition test: it is flammability and give blue flame
- Iodoform test:yellow precipition appears
- Oxidation with potassium dichromate change the color of solution from orange to green.

6- Heat of combustion results:

- $Q=m\times c\times \text{delta } t$

  $=65\times1\times47$

  So, $Q=3055$

- Mass of burned (ethanol)=100-96,2=3,8 g
- No of moles of ethanol= 3.8/46=0,0826 moles

0,0826. → 3055

1mole. → H (heat of combustion)

H =1×3055÷0,0826=36,985 kg/mol

The heat of combustion value of ethanol in our experiment was lower than the standard value of approximately -1367 kJ/mol. This decrease in value can be attributed to several factors, including that the experiment was not sufficiently isolated, and the use of simple tools instead of specialized equipment designed for this experiment.

7-conclusion:

The study concluded that utilizing fruit and vegetable waste represents an effective method for bioethanol production, contributing to solving the issue of organic waste management and providing a cleaner fuel alternative. Experiments demonstrated the successful conversion of sugars present in this waste into bioethanol using yeast. Notably, the bioethanol produced from fruits and vegetables exhibits improved combustion characteristics, with the indication that fruits often contain higher sugar levels, making them a promising source for bioethanol production.

8-Acknowledgment:

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